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(54) Sheet levitational support.

(57) An array of acoustic transducers (100) is operated to generate progressive air pressure waves. Sheets (106, 107) are introduced by feed rolls (105) and reflect the progressive waves to establish interference and a pattern of standing waves which includes a planar array of high pressure antinodes to support a sheet against gravity approximately at the level of a planar array of low pressure nodes. The initial portion of the array of transducers is horizontal to provide levitational support. A succeeding portion is inclined to the horizontal to provide movement under gravity for the sheets to a bin (112).

The height of support by the standing waves may be changed by altering the frequency, and they may be rendered non-supporting by turning off or greatly reducing the amplitude of the standing waves. Various controls and guides may be provided to direct sheets being transported.

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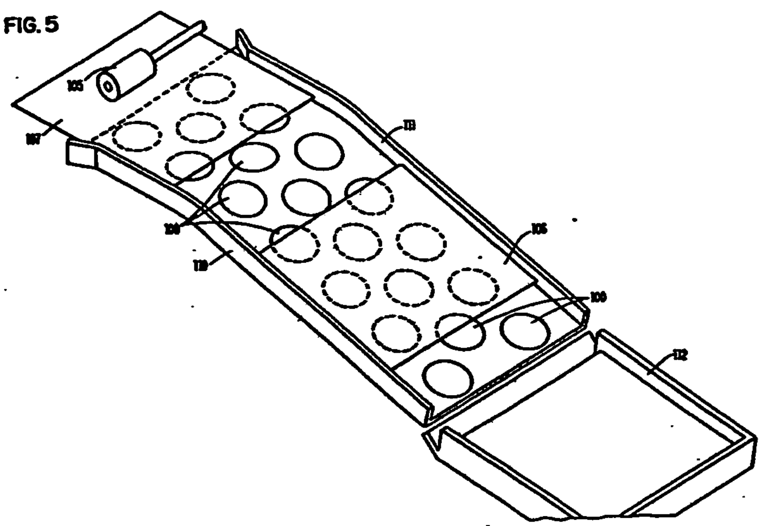
FIG. 5



SHEET LEVITATIONAL SUPPORT

The invention relates to levitational support of planar objects, such as sheets.

The transport of planar objects, such as sheets, or objects having a planar support base is normally accomplished by means of mechanical apparatus, such as rollers or belts.

Mechanical apparatus of this type is subject to wear, often requires complex apparatus to supply mechanical energy, and involves mechanical contact with the objects. In instances where contact with the object has been an extreme problem, such as the transport of semi-conductor wafers, pressurized air has been used to float the objects.

Such an air pressure system is disclosed, for example, in US 3,588,176, in which pressurized air is supplied to a duct via a porous bottom wall to form an air film for suspending articles to be transported.

Pressure air jets have also been employed to support articles for transport. An example is shown in US 4,131,320, in which pressure air jets both support articles and are directed to provide a force component in the direction of motion of the articles.

Pressurized air systems, however, require pumps and ducting to create and properly direct and control the pressurized air.

It has been proposed in a paper by R R Whymark, "Acoustic Field Positioning for Containerless Processing", Ultrasonics, November 1975, pages 251-261, to use a single sound transducer to support small spherical or disc-shaped objects.

Simply holding such small objects in place without gravity is useful

but is not helpful in the support and transport planar objects, such as sheets.

Further, none of the above systems provides a simple and relatively friction-free way of transporting planar ojbects, such as sheets.

In accordance with the present invention, apparatus and method are provided for supporting planar objects with standing pressure waves in a compressible medium. The standing waves support a planar object approximately at low pressure nodes thereof and transport is accomplished along a common plane established by the low pressure nodes.

The scope of the invention is defined by the appended claims, and how it can be carried into effect is hereinafter particularly described with reference to the accompanying drawings, in which :-

FIGURE 1 is an isometric view of a sheet levitational support according to the invention;

FIGURE 2 is a diagrammatic side elevation view of the support of Fig.1;

FIGURE 3 is a side elevation of part of another embodiment of the invention;

FIGURE 4 is a side elevation of part of yet another embodiment of the invention;

FIGURE 5 is an isometric view of an embodiment of sheet transport apparatus according to the present invention;

FIGURE 6 is a diagrammatic side view of the apparatus of Figure 5;

FIGURE 7 is a diagrammatic side view of another embodiment of sheet transport apparatus according to the invention;

FIGURE 8 is a partial isometric view of still another embodiment of sheet transport apparatus according to the invention;

FIGURE 9 is a diagrammatic side view of part of the apparatus of Figure 8;

FIGURE 10 is a diagrammatic isometric view of a further embodiment of the invention.

In one embodiment of the invention, a sheet 10 (Figs. 1 and 2) is supported for transport by piezoelectric transducers 12, 14 and 16 mounted on a support plate 17. The plate 17 is connected to ground 18 to serve as an electrical ground for the bottom surface for each of the transducers 12, 14, and 16. The upper surface of each of the transducers is connected electrically by wires 19 to driver 20.

The driver 20 supplies an electrical signal at a desired frequency and amplitude, via wires 19, to the transducers. The electrical signal causes the transducers to expand and contract in accordance with the applied signals. The resultant expansion and contraction thereof in the vertical direction produces vibrations in the air or other compressible medium immediately thereabove. Thus the transducers generate progressive waves which, if subject to intereference from progressive waves of the same frequency and kind, produce standing waves. Such interference may be provided by a separate source of progressive waves or by reflection of the progressive waves from the transducers, either from a separate reflector or from a sheet to be supported, as in the present embodiment. So long as the frequency of the signal supplied by driver 20 remains constant, each tansducer produces a separate set of standing waves in the air immediately thereabove. "Standing waves" are defined in Harris, Handbook of Noise Control, McGraw-Hill Book Company, 1957, pages 1-15, as "periodic waves having a fixed distribution in space which is the result of interference of progressive waves of the same frequency and kind. Such waves are

characterized by the existence of nodes or partial nodes and antinodes that are fixed in space." The standing waves are represented in Fig.2 by lines representing high pressure antinodes and low pressure nodes within the standing waves. Lines 22, 24 and 26 represent high pressure standing wave antinodes produced by transducers 12, 14 and 16, respectively. Lines 32, 34 and 36 represent the low pressure nodes of the standing waves produced by transducers 12, 14 and 16, respectively. The shorter length of lines 32, 34 and 36 as compared to the lines representing antinodes 22, 24 and 26 is representative of the fairly rapid attenuation of the standing waves as a function of the distance from the transducers. Lines 42, 44, and 46 represent, respectively, second high pressure antinodes of the standing waves produced by the transducers 12, 14 and 16. These lines are even shorter than those immediately below and indicate the further attenuation of the standing waves as function of the distance from the transducers. Sheet 10 is supported at approximately the first low pressure nodes of the standing waves. Were gravity not a factor, the sheet would be exactly centred at the first low pressure nodes. However, with the effect of gravity, the sheet actually appears to be supported slightly below the centre point of the first low pressure nodes. Sheets and similar objects appear to be especially adapted for support in this manner, because the entirety of the object lies within the low pressure region of the standing waves. Further, the sheet itself, being linear, serves as a reflector to reflect the progressive waves back to the transducer, thereby reinforcing the standing waves.

Transport of the sheet 10 is accomplished by a rotary solenoid 48. When the solenoid is actuated, an arm 49 thereon is rotated in the direction of arrow 50, contacting an edge of sheet 10 to impart movement thereto in the direction of arrow 51.

In order to support the sheet 10 as it continues down a transport path from the support area illustrated in Fig.1, additional acoustic transducers may be provided.

The minimum number of transducers required to support a planar object is three as illustrated in Figs. 1 and 2. These generate progressive waves which when subject to appropriate interference produce standing waves with a stack of essentially planar arrays of high pressure anti-nodes and low pressure nodes. As the stiffness, or beam strength, of the object is reduced, the spacing between transducers for still supporting the object will have to be reduced. As the transducers are brought closer together to compensate for lower beam strength of the object, the number of transducers must correspondingly be increased to support the entirety of the object. Many studies exist which will assist in determining the greatest separation between transducers for supporting planar objects. An example is contained in Timoshenko and Woinowsky-Krieger, Theory of Plates and Shells, Second Edition, McGraw-Hill Book Company, 1959, Pages 245-250. Given the non-uniformity of paper sheets to be transported, and the complexity of the formulae involved to calculate the spacing, it appears that the spacing is best determined experimentally using the formulae as a guidance. The amplitude of the signal from driver 20 to support an object 10 depends upon the efficiency of the transducers, the density of the compressible medium, the number of transducers, the weight supported by each transducer, and the precision of control desired over the vertical positioning of the object 10. Once again, the precise amplitudes desired are best determined experimentally.

In another embodiment of the invention, a piezoelectric crystal transducer 52 (Fig.3) is secured to a grounded support plate 54 and has its top surface electrically connected by line 55 to a driver 56. Another grounded support plate 63 is spaced above the plate 54 and a second piezoelectric crystal transducer 62 is mounted on the bottom thereof and has its bottom surface electrically connected by wire 65 to a second driver 66. Transducers 52 and 62 must be driven in synchronism, so a line 67 interconnects the drivers 56 and 66 to ensure that both drivers operate in synchronism. Alternatively, a single driver may be utilized to provide the excitation signals to

both transducers 52 and 62.

The frequency of the signals supplied from the drivers to the piezo-electric crystal transducers 52 and 62 must be at exactly the proper frequency so that each generates a standing wave of exactly n wave lengths between itself and the opposite transducer. For this purpose, the frequency may be adjustable or the spacing between the transducers may be adjustable. Thus, the standing waves generated by each transducer reinforce those generated by the other to provide a strong and uniform standing wave. As illustrated, the resultant common standing wave includes low pressure nodes 70, 71 and 72.

A planar object may be supported by any one of the low pressure nodes in the common standing wave. A plurality of the sets of piezo-electric crystal transducers may be arranged such as illustrated in Fig.1 for supporting planar objects such as sheets.

In another embodiment of the invention, another type of transducer is used, which resembles an audio speaker and is therefore called a voice coil transducer. The transducer comprises a voice coil 80 (Fig.4) supported by a bracket 81 on a chassis 82. The voice coil 80 is connected by wires 87 to a driver (not shown) similar to driver 20 (Fig.2). A plunger 84 is vibrated by the application of electrical signals to the voice coil 80. The plunger is connected to a planar element 85, comparable to a "speaker".

Vibration of element 85 by the voice coil produces progressive waves in the compressible medium immediately thereabove. A reflective plate 96 is positioned an exact number of wave lengths from element 85. In this position, the plate 96 serves as a reflector to reflect back progressive waves to interfere and set up standing waves. The resultant standing waves include high pressure antinodes 90 and 91 and low pressure nodes 92. A sheet or planar object to be supported

would thus be placed at low pressure node 92. To support an extensive object such as a sheet, a plurality of such transducers would be arranged in an array similar to that of Fig.1.

Figures 5 and 6 illustrate a complete sheet transport system employing a large array of acoustic transducers 100. The transducers 100 may be of any suitable type, for example the piezoelectric crystal transducers of Figs. 1 and 2 or the voice coil transducers of Fig.4. All the transducers are connected in common to a driver 102 and are driven at the same frequency and amplitude. Nip rolls 104 and 105 are positioned to form a nip at approximately the low pressure node. The nip rolls deliver sheets, such as sheets 106 and 107 through the nip. The sheets are then supported by the standing waves from transducers 100. The inertia given to the sheets by the nip rolls 104 and 105 propels each of the sheets in the direction of arrow 108. Side guides 110 and 111 are provided to guide the sheet along the path formed by the transducers 100.

The transport path formed by the transducers need not be level, and is illustrated in Figs. 5 and 6 as being at first level and then curving downwardly. As sheet 106 is propelled downwardly along the transport path, gravity assists the motion of the sheet in overcoming any friction with guides 110 and 111. The sheets may then be supplied to a station at the end of the transport path, which may comprise a bin 112.

In another sheet transport system, two sets of transducers 120 and 121 (Fig.7) are provided. The output of a driver 123 is connected by lines 128 to transducers 120 and to relay 124. The output of another driver 125 is connected by line 130 to a second input to relay 124. The output of the relay 124 is connected by lines 129 to transducers 121. A two-position switch 127 is connected to and operates relay 124. With switch 127 in a first position, relay 124 connects output

lines 128 from driver 123 to lines 129 leading to transducers 121. With switch 127 in the second of two positions, relay 124 connects output line 130 from driver 125 to input lines 129 to transducers 121. Driver 123 operates at first frequency "F1", and driver 125 operates at a second frequency "F2" which is a higher frequency than "F1". With switch 127 initially in the first position, all transducers 120 and 121 are driven at the same frequency "F1" from driver 123. A sheet 132 is therefore supported equally by all transducers, and is level as shown by dotted line 133. Changing the switch 127 to the second position, operates relay 124 to transfer from driver 123 to driver 125 to operate the transducers 121. These transducers are driven at the higher frequency "F2". The higher frequency reduces the wave length, therefore reducing the height of the low pressure nodes of the standing waves. The lower heights of these nodes draws sheet 132 downwardly as shown by the solid line 134. When the sheet is drawn downwardly in this fashion, gravity may cause the sheet to move along the node positions in the direction of arrow 135 and into bin 137.

Thus, the selection of different frequencies for the transducers can effect translation and movement of the object supported thereby.

In another embodiment of sheet transport system, an array of transducers 140 (Figs. 8 and 9) is provided, together with additional transducers 141 and 142. A friction pad 144 and two edge guides 145 and 146 are also provided. A single driver 150 operates all the transducers, with an on-off switch 151 interposed between the driver and transducers 141. A sheet 153 moving in the direction of arrow 154 is supported by transducers 140. Should switch 151 be on, the output from driver 150 is also supplied to transducers 141. With transducers 141 also supporting the sheet, it continues in the direction of arrow 154 across the entire array. Upon selectively turning switch 151 off, no signal is supplied to transducers 141. Thus, upon reaching transducers 141, the sheet is no longer supported

at the leading corner of sheet towards edge 145. Not being supported, the sheet dips or flexes due to the force of gravity downwardly and into contact with friction pad 144. Friction pad 144 thereby engages the corner of the sheet, while the inertia of the movement of the sheet tends to move the centre of gravity thereof in the direction of arrow 154. The sheet therefore begins to pivot about friction pad 144 in the direction of arrow 160 until leading edge 158 is stopped by edge guide 145 and side edge 162 is stopped by guide 146. These guides tend to stop rotation of the sheet and hold the sheet 153 stationary.

At a subsequent time, switch 151 is turned on to supply the driver output to transducers 141. Application of this output causes transducers 141 to elevate the leading edge 158 of sheet 153. Driver 150 is also connected to transducers 142 which are slightly lower than transducers 140. Thus, when the leading edge 158 of sheet 153 (now in fact the trailing edge) is elevated by transducers 141, the other end of the sheet supported by transducers 142 is slightly lower. Gravity therefore tends to move sheet 153 in the direction of arrow 162. Therefore, selectively operating switch 151 results in a change in direction of the movement of sheet 153 to a different path.

Another application of the present invention is illustrated in Fig.10. An array of acoustic transducers 170 is provided and driven by a driver (not shown) to generate progressive waves. A sheet 173 having thereon a substance requiring drying, such as ink on a printed sheet, is released over the array. Gravity moves sheet 173 in the direction of arrow 174. The sheet 173 reflects the generated progressive waves and standing waves are set up. The sheet 173 continues to fall until it reaches a low pressure node of the standing waves capable of supporting the sheet. Heat sources or drying elements 175 dry the substance as the sheet is dropping as well as whilst it is supported by transducers 170. Thus, transducers 170 act to provide a non-contact

cushion, preventing smearing of the non-dry substance. When the substance is dried, the sheet may be propelled in the direction of arrow 176 by means of a transport initiator, such as rotary solenoid 48 in Fig.1, or removed by a suction pad upwardly.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention.

In an array of sheet support transducers, those around the edges could be driven at lower frequency, tending to centralise the sheet.

The effect of termination may be achieved by a reduction in amplitude or an increase in frequency.

CLAIMS

1 A sheet levitation support system comprising transducer means (12,14,16; 52; 80,84,85; 100; 120,121; 140,141,142; 170) for generating air pressure waves, and drive means (20; 56,66; 102; 123,125; 150) for driving the transducer means to generate progressive waves which, when subject to interference, form a stack of essentially planar arrays of high air pressure standing wave antinodes (22,24,26,42,44,46; 90,91) and of low air pressure standing wave nodes (32,34,36; 70,71,72; 92) to support a sheet (10; 106,107; 132; 153; 173).

2 A system according to claim 1, including means (48,49; 104,105) for moving sheets in one of the air pressure node arrays.

3 A system according to claim 2, including guide means (110,111) for guiding sheets supported in one of the air pressure node arrays.

4 A system according to claim 1, 2 or 3, including interference means (62; 96) for providing air pressure waves in the opposite direction as and directed towards the transducer means for establishing the high air pressure antinodes and low air pressure nodes.

5 A system according to claim 4, in which the interference means comprises an air pressure wave reflector (96).

6 A system according to claim 4, in which the interference means comprises second transducer means (62) for generating air pressure waves.

7 A system according to any preceding claim in which the transducer means comprises an array of separate transducers.

output

8 Sheet transport apparatus comprising a system according to claim 2, or any claim appendant thereto, including directing means for imparting movement to the sheet essentially laterally of the stack of nodes and antinodes of the standing waves.

9 Sheet transport apparatus comprising a system according to claim 2, or any claim appendant to claim 2, including wave generating transducer means which generates a non-horizontal essentially planar array of air pressure antinodes and nodes whereby gravity may effect movement of the sheet (Figs. 5 and 6).

10 Sheet transport apparatus comprising a system according to claim 2, or any claim appendant to claim 2, including means (127; 151) for selectively altering the plane of support with respect to a horizontal direction.

11 Apparatus according to claim 10 in which the selective alteration means comprises means (151) for selectively terminating the drive to at least one of the transducer means.

12 Apparatus according to claim 11, including drag means (144) for exerting a drag on a sheet over the transducer means whose drive is selectively terminated.

13 Apparatus according to claim 10, in which the selective alteration means comprises means (125,124,127) for selectively altering the drive frequency to at least one of said transducer means.

14 A method for levitationally supporting a sheet, comprising the steps of generating standing waves in a compressible medium to support by a planar array of high pressure antinodes, a sheet at approximately a planar array of low pressure nodes.

15 A method of sheet transport, including a levitational support method according to claim 14, including directing a sheet essentially laterally of the standing waves along approximately the low pressure node array.

16 A method according to claim 15 in which movement is imparted to the sheet laterally of the standing waves.

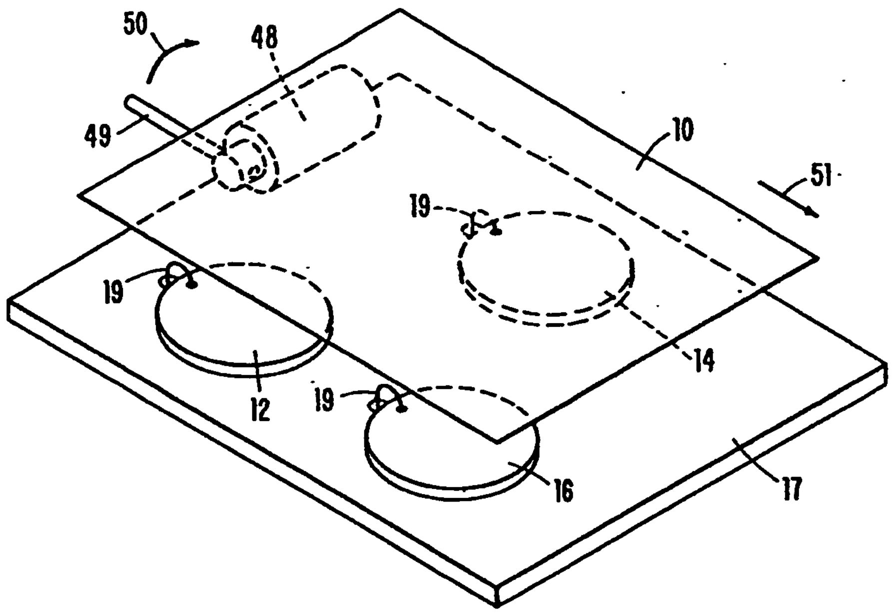
17 A method according to claim 16, in which standing waves are generated including an array of low pressure nodes whose plane is non-horizontal, whereby gravity may effect movement of the sheet.

18 A method according to claim 16 in which at least part of the array of low pressure nodes is selectively controlled to effect movement of the sheet.

19 A method according to claim 18, in which the selectively control is to terminate part of the standing waves.

20 A method according to claim 18, in which the selective control is to alter the wave length of part of the standing waves.

FIG. 1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48
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10
51
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12
19
16
17

FIG. 2

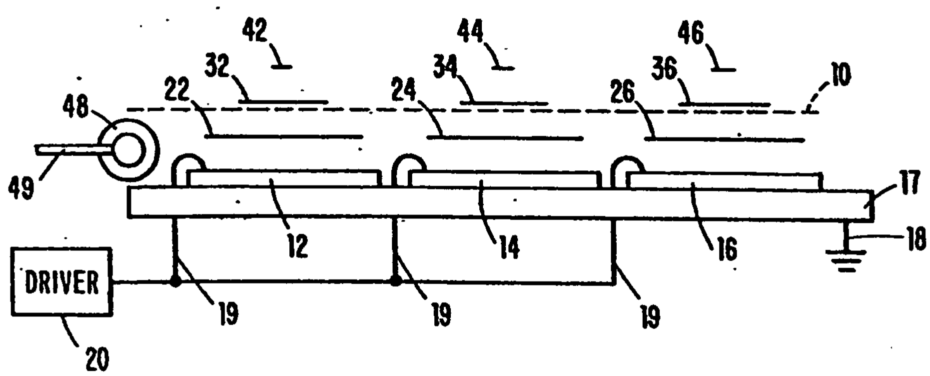

42
44
46
32
34
36
22
24
26
10
48
49
17
12
14
16
18
DRIVER
19
19
19
20

FIG. 3

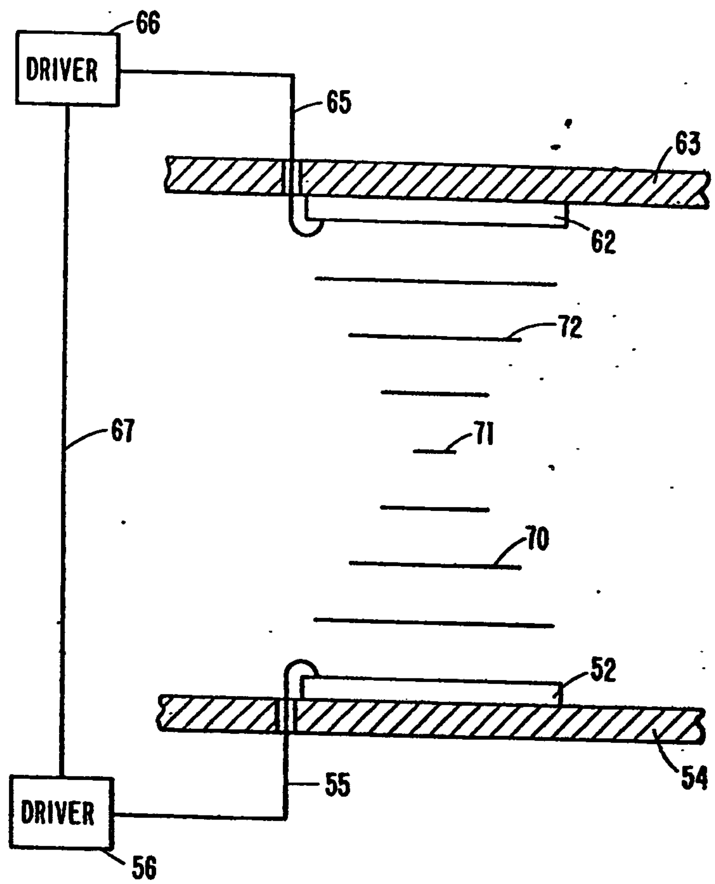
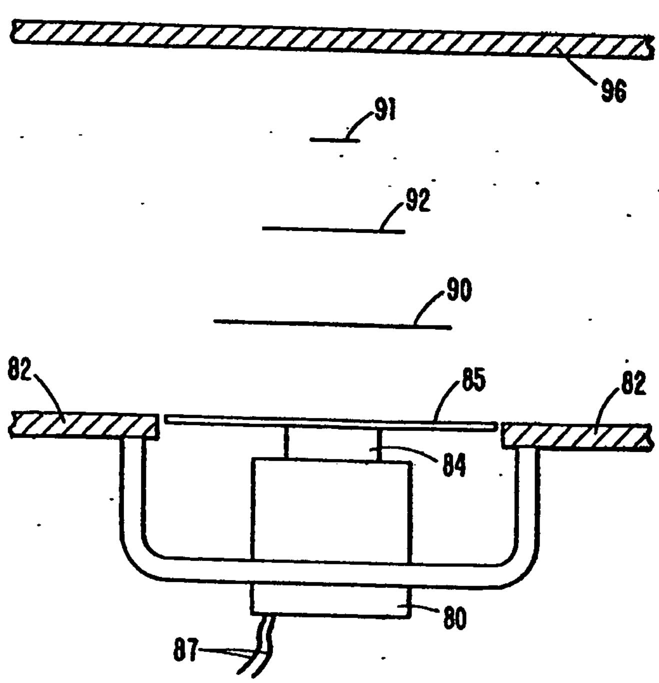

DRIVER
66
65
63
62
72
71
67
70
52
54
DRIVER
55
56

FIG. 4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87

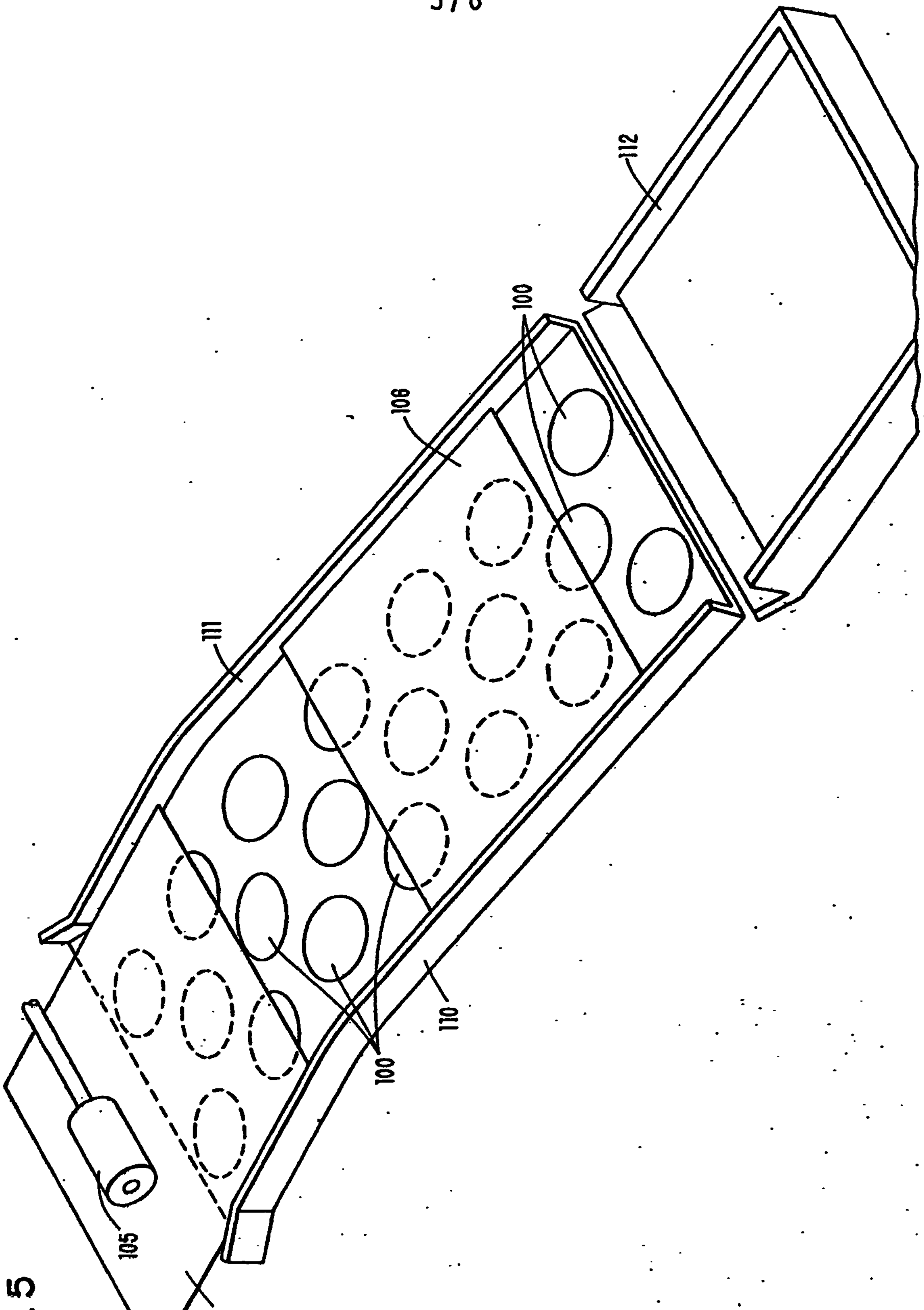


FIG. 5

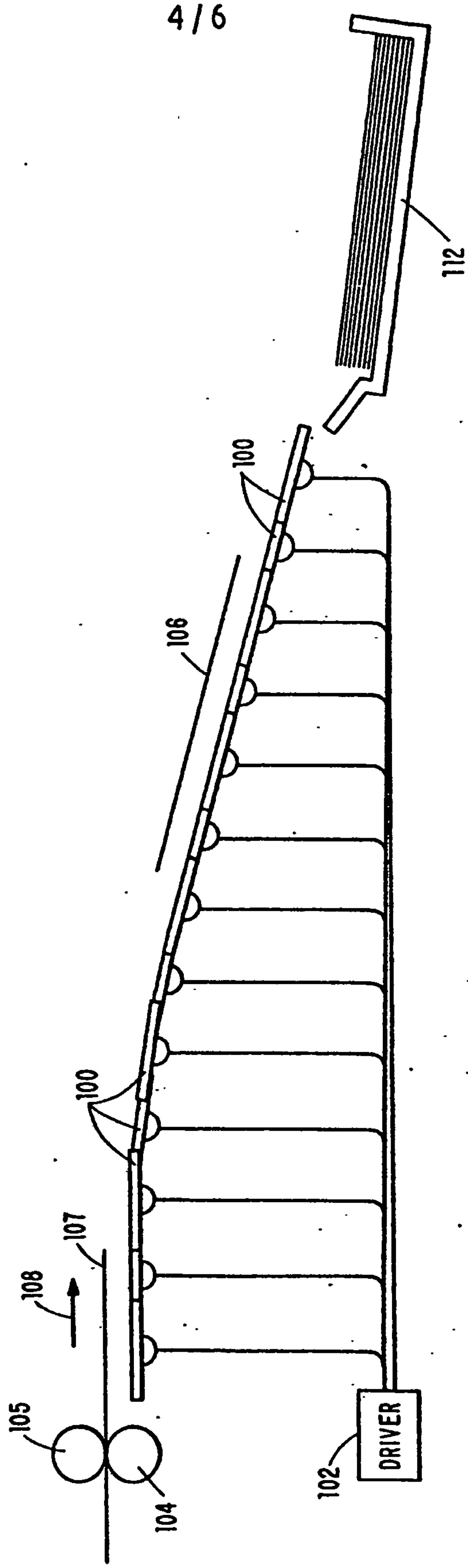


FIG. 6

FIG. 7

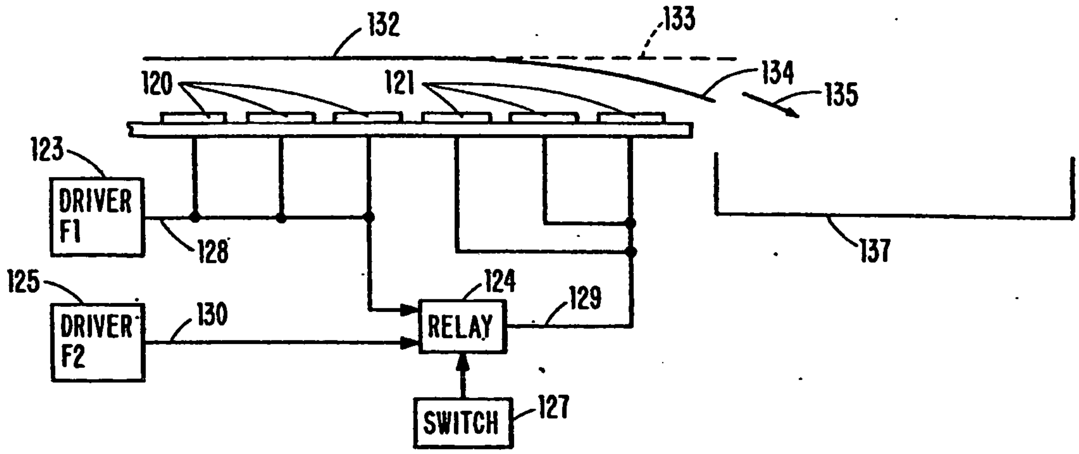
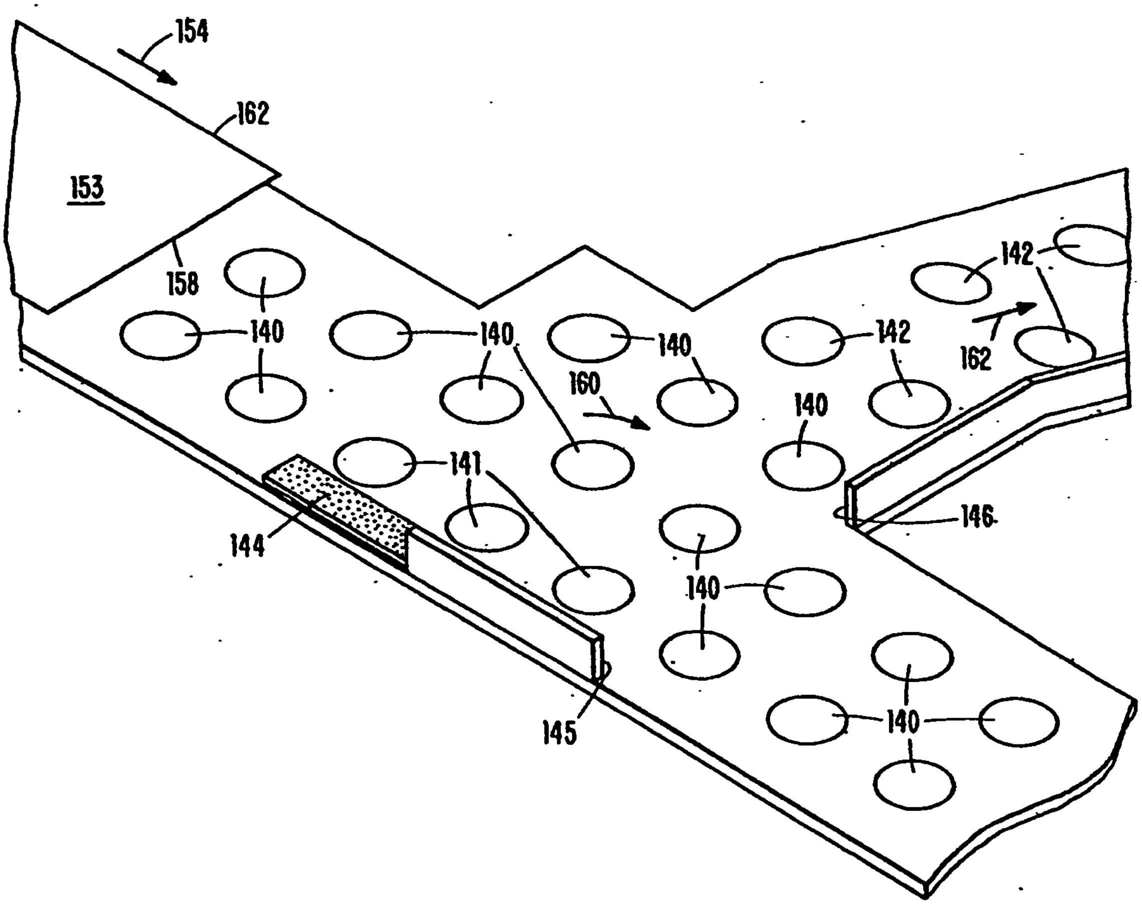

132
133
120
121
134
135
123
DRIVER F1
128
137
125
DRIVER F2
130
124
RELAY
129
SWITCH
127

FIG. 8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162
153
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140
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142
160
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144
145
146

FIG. 9

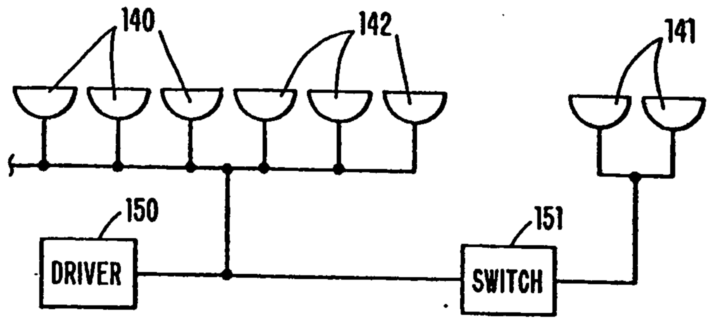
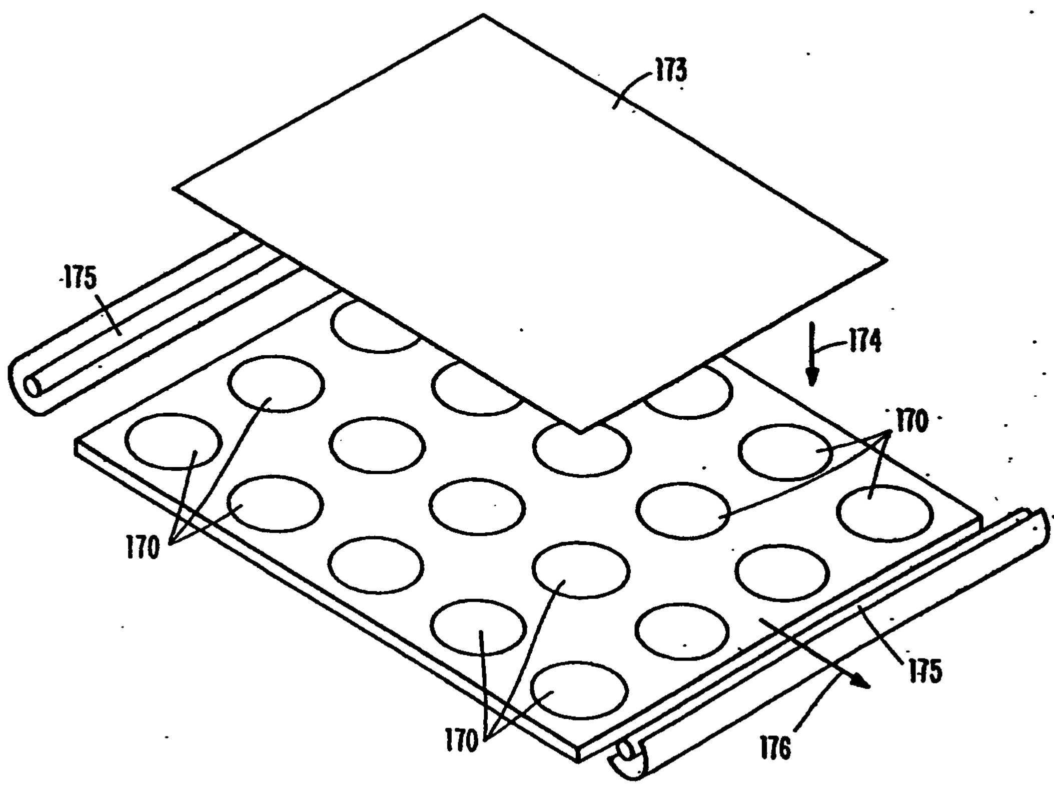

140
142
141
150
DRIVER
151
SWITCH

FIG. 10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176
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European Patent Office

EUROPEAN SEARCH REPORT

0064593

Application number

EP 82 10 2509.5

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
A	DE - A - 2 251 592 (DEMAG)	
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A	US - A - 3 717 801 (SILVERBERG)	
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D,A	US - A - 4 131 320 (VOLAT et al.)	
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D,A	US - A - 3 588 176 (BYRNE)	

CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)

B 65 H 5/22

TECHNICAL FIELDS SEARCHED (Int.Cl. 3)

B 65 H 5/00
B 65 H 29/00
B 65 H 17/00

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
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T: theory or principle underlying the invention
E: earlier patent document, but published on, or after the filing date
D: document cited in the application
L: document cited for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Berlin	18-06-1982	KLITSCH

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